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AN OBJECTIVE LENS HYDROSPECTRONEPHELOMETER FOR MEASURING "IN SITU" THE OPTICAL CHARACTERISTICS OF SEA WATER

B. F. Kel'balikhanov and E. I. Karsovskiy

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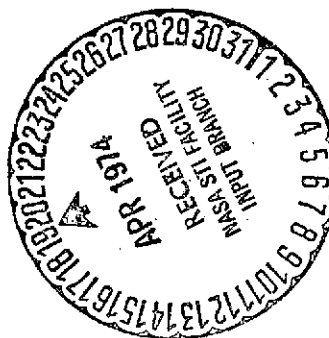
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16. Abstract

The paper presents a description of the meter for measuring "in situ" the scattering indictrix within little angles 0,1 - 2°. The results of the measurements made by these and the serial meter of the type SGN-57 are presented. The measurements were conducted in the Black Sea.

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AN OBJECTIVE LENS HYDROSPECTRONEPHELOMETER
FOR MEASURING "IN SITU" THE
OPTICAL CHARACTERISTICS OF SEA WATER

B. F. Kel'balikhanov and E. I. Krasovskiy

The indicatrix of the scattering of light is one of the /113*
important optical characteristics it is necessary to know for
solving many theoretical and applied problems of the hydro-
system. Measurements of the indicatrix of scattering in sam-
ples of water can give the distortion [sic] results owing to
physical and chemical changes occurring in water with its
upsurge on the surface.

The need for natural settings in experimental determina-
tion of this characteristic is manifest for a high-grade es-
timate of the results of research. Not many devices are
known for measuring the indicatrices of light scattering by
sea water "in situ" [2-5]. The nephelometer discussed in
article [2] was intended for the measurement of the scatter-
ing of light at critical angles of 3° to 163°, with steps
of 5°. In the nephelometer presented in article [3], meas-
urements of the scattering of light are conducted at 12 fixed
angles: 10°, 20°, 30°, 45°, 60°, ..., 165°. A nephelometer /114
with a laser source of light permitting measurements to be
made at fixed angles (1°, 2.5°, or 3.5° by means of a shift
of the optical system), and further on from 25° to 135°, is
discussed in article [4]. The most refined nephelometer that
has appeared was reported on in article [5]. It permits
scattering to be measured at angles from 1° to 170°. However,
this nephelometer is designed for installation on a supply
boat and is not constructed for operation from expedition
boats.

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*Numbers in the margin indicate pagination in the foreign text.

Not one of all the nephelometers enumerated reaches the region of angles less than 1°. At the same time, it is necessary to know the indicatrix of scattering in regions of small angles (less than 1°) for a number of applications: for example, the calculation of light fields of a narrow-beam source and the derivation of the distribution of hydrosol according to size by solving the inverse problem.

In the last year nephelometers have been developed and tried out which permit indicatrices of scattering to be measured at critical angles from 20' up to 5–7°. In particular, a nephelometer was discussed in article [6] which subsequently was modernized by colleagues at the Institute of Oceanology, Academy of Sciences, U.S.S.R. An apparatus has appeared from this laboratory and measurements made in samples of water. A nephelometer "in situ" was discussed in article [7]. A linearly polarized source of light (ruby laser) was used in the apparatus.

The principle of operation of our proposed nephelometer "in situ" is similar to the laboratory meter of K. S. Shifrin and V. I. Golikov [6]. In contrast to the above enumerated apparatuses, our described nephelometer allows the indicatrices of scattering to be measured "in situ" in a wide spectral range (340–760 nm) with a spectral resolving capacity not worse than 4 nm in the critical angles of 0.1 to 2.3°. The apparatus is intended for operation on a cable line at a depth of 200 meters.

It is possible with the device to measure, besides the indicatrix of scattering, the index of attenuation in different parts of the spectrum, and thus to obtain the information needed for an estimate of the transfer of light energy in a hydrous medium.
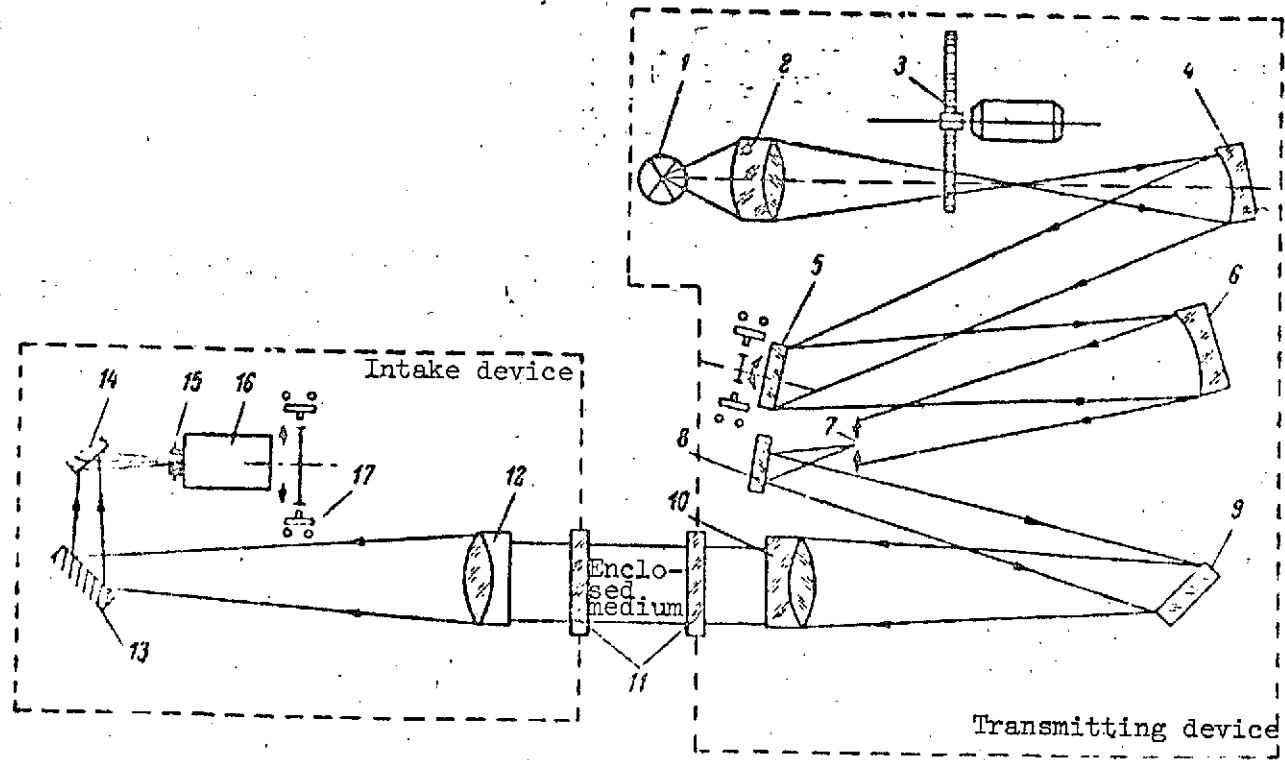
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Fig. 1. Principal optical scheme of a hydrospectronephelometer.
(Explanation in text)

In Fig. 1 the principal optical scheme of the immersed part of the apparatus is presented. The light flux from the transmitter 1 with the help of the condenser 2 is focused on the pattern of the modulator 3, playing the role of entrance slit. The diverging modulating light flux is transformed in parallel by the objective 4 and projected onto the diffraction grating 5. The dispersed light flux reflected from the grating, falls on the spherical mirror 6, in the focal plane of which is set up the exit slit 7.

It is possible to obtain the light flux of a distinct spectral structure by means of a scanning grating at the exit slit 7. The degree of monochromaticity in this case is determined by the number of hatches of the grating, by the parameters of the optical system, and by the size of the exit slit. /116 The pattern from slit 7 of the part of light flow is directed with the aid of the mirrors 8 and 9 at the objective 10 and, proceeding through the protective illuminator 11, exits in the medium to be analyzed. The light flow proceeding through the medium and illuminator 11 of the intake block is focussed in the mirror lens of the system 12, 13, and 14 in the diaphragm slit. The diaphragm is rigidly bound to the photoelectric multiplier 16 of the type FEU-51 and constitutes a system of analyzer of the intake block. The analyzer linearly scans in the focal plane of the objective 12 and thereby photometrically scans the light flux in this plane. The linear scanning of the analyzer is converted into an angular scanning and applied to the scale of the intake selsyn in the console.

The electric signal plotted from the charge of the FEU through the cable of the coupling enters the console where it is amplified in corresponding form and is impressed on an automatic writer of type EPP-09. Thus, the recordograph recorded

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on the EPP-09 characterizes the distribution of the light flux in the focal plane of the objective 12 of the intake block as a function of the scan angle of the analyzer.

The assembly of the apparatus, the principal optical scheme of which is presented in Fig. 1, consists of a block immersed in water of the coupling of a cable with the panel of the registration signal and the remote control panel with the device as a whole.

All the operations realized in the immersed part of the apparatus are controlled from the console with the aid of the indicator lamp.

The blocks of the transmitter and receiver are placed in an air-tight pressure chamber and coupled to the console by a cable of the type NRShM. In addition the blocks of the receiver and transmitter are coupled mechanically with the aid of a partitioning cylindrical tube with apertures for the intake of water and are fastened coaxially one with the other. A base is set between the receiver and transmitter by a number of sections and is adjusted provisionally on the basis of the anticipated transparency of the medium in question.

The indicatrix of diffusion is measured in the following fashion: The light flux "dry" is photometrically scanned from the apparatus submerged in the water. With this in the focal plane of the objective (Fig. 1, 12) the patch of the final diameters is scanned photometrically. Under the indicated conditions, the medium, in fact being "optically" clean, does not superimpose any kind of distortions. After this, the apparatus is submerged at the assigned depth in the medium to be analyzed. The original image distorts the light patch and deforms it because of the presence of the scattering properties of the

medium. The degree of deformation will be higher, the stronger the scattering properties of the medium. Both the diffused and the direct light flux is scanned photometrically by the next scanning of the analyzer in the receiver apparatus. The over-lapping of the recordograph of the distribution of the light field of the "dry" device and of the distorted field in the medium being investigated permits it to be released from the direct light flow. The difference remaining carries information concerning only the scattering properties of the medium and characterizes the indicatrix of scattering.

The index of attenuation, in addition to the indicatrix of scattering can be measured. Readings are made for this from the recordograph of the determination of the light flux of the "dry" device and of the distortion in the medium corresponding to the null position of the angle of scanning of the analyzer. A further value of the index of attenuation is computed according to the formula

$$\varepsilon = \frac{1}{L} \lg \frac{F_o}{F_x}$$

on the basis of the Buger Law expressed for the ideal case, namely, for monochromatic parallel radiation.

Here L is the distance between the intake and the radiator; F_0 and F_x are the magnitudes of the light flux for the "dry" apparatus and the apparatus immersed in water, respectively.

The actual beam has a dispersion distinguished from the null point. The assumption of the experiment and of the estimate show that an increase of the dispersion of the beam from 1 angular minute to 1° is not substantially expressed in the change of the index of attenuation and is within the limits

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of the error of measurement (10%). We obtain this conclusion for the case when the measurements are carried out by a basic method of comparison. But for this method, based on a comparison of the results of a measurement in air with the results of a measurement in water, it is necessary to use the formula

$$\varepsilon = \frac{1}{L} \lg \left(pq \frac{F_o}{F_x} \right),$$

where p-1.081 [sic] is the coefficient taken into account of the difference of the light loss upon reflection at the boundary of the air-water and water-glass interfaces. This coefficient is calculated according to the Fresnel formula; q is the coefficient taking into account the variation of illumination of the output illuminator during the transition from a measurement in air to a measurement in water, determined by the empiracal formula

$$q = \frac{(D_o + L\alpha)^2}{(D_o + \frac{L\alpha}{n})^2},$$

where D_0 is the diameter of the light beam of the output illuminator; α is the angle of dispersion of the light beam in air; and n is the index of refraction.

Thus the distinguishing characteristic of the described apparatus consists of the use of an analyzer of luminous energy consisting of a diaphragm and the FEU, together scanning the focal plane of the optical intake system in combination with a diffraction grating, permitting the indicatrix of scattering and the index of attenuation to be measured in a narrow band of any part of the visible region of the spectrum.

Principal (Optical) Parameters of the Apparatus

1. The diffraction grating is planar b x h = 25 x 25 mm^2. N = 500 hatches/mm;

2. The focal length of the mirror and lens objectives is f = 500 mm.

3. Entrance and exit slits are d = 0.5 mm;

4. The size of the diaphragm of the analyzer of the intake unit (set) d_a = 0.05, 0.1, 0.5 mm;

5. The dimension of the light beam in the focal plane of the objective (12, in Fig. 1) of the input unit is d_n = 0.8 mm;

6. The linear path of the analyzer l = ±20 mm.

The result of the measurement by the described apparatus of the scattering in the range of 0.1 to 2° is presented in Fig. 2. Simultaneously the indicatrix of diffusion is measured in the range of 1 to 160° with the aid of a series device of type SGN-57.

Measurements were conducted together with colleagues of the Laboratory of Hydrooptics of the Institute of Oceanology, Academy of Sciences, U.S.S.R.

The results of the measurement of the scattering properties of the medium at small angles were calculated according to the formula

$$G(\gamma) = c \ \frac{dF(0)}{dF(\gamma)} \ ,$$

where c is a constant of the apparatus, determined by optical parameters of the intake unit such as f, L, and d_a, and is equal to 1.07×10^4; F(0) and F(γ) are the magnitudes of the signals measured at values of the angle γ = 0 and γ = 0.1 to 2°, respectively.

Measurements were conducted with the position of the diffraction grating corresponding to a wavelength of 0.53 micron and width of the spectral band of the radiation of 4 nm. An interference light filter is used with this in apparatus SGN-57 at the same wavelength but with a width of the transmission band of 10 nm.
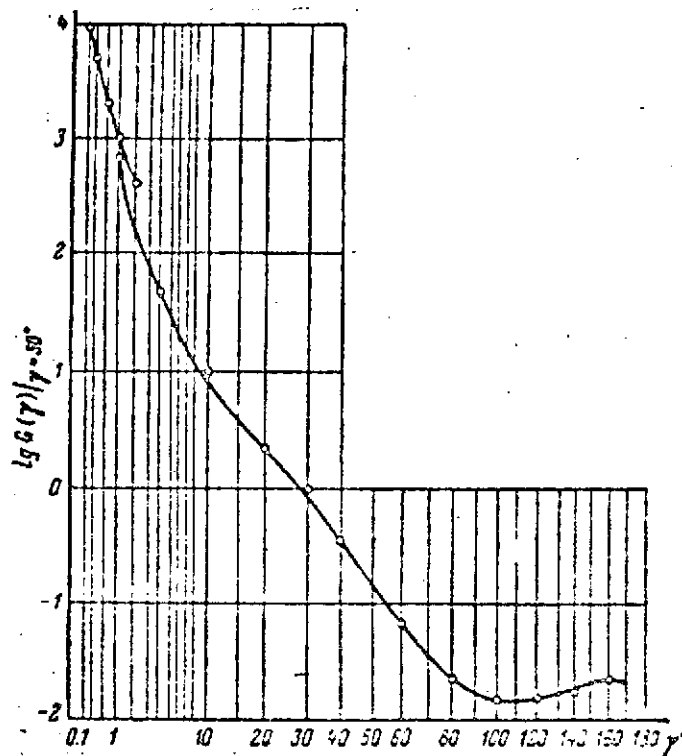
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Fig. 2. Indicatrix of scattering measured by a hydrospectro-
nephelometer in the region of angles of 0.1 to 2° and standard
deviation of meter of type SGN-57 in the region of angles
1°–160°.

Thus, in angles from 1 to 2° the indicatrix of scattering
is measured twice by different apparatuses. The character of
the slope of the curves in this part of the angles has an un-
important deviation. It is possible to deduce only the set of
statistical material as far as a similar extrapolation to a
comparison of the results of measurements of 2 different ap-
paratuses. Here the result is reduced from a single measure-
ment.

It is evident that the region of the indicatrix of
scattering from 0.5 angular minutes can be calculated after
introducing into the apparatus a number of structural changes:

for example, a decrease of the diaphragm of the analyzer up
to the threshhold value determining the emergence of the dif-
fraction diagram with the corresponding strengthening of the
clarity of the radiation; or up to a decrease of the aperture
of the beam of radiation; or up to an increase of its di-
rectional effects, and a number of others.

Our described apparatus was tried in the Southern Division
of the Institute of Oceanology of the Academy of Sciences,
U.S.S.R. and showed the theoretical possibility of its use
for radiation of optical characteristics of an aqueous medium
"in situ."

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